

## 2.5 IDENTIFICATION OF KEY DO THRESHOLDS

DRBC culled the literature and identified three types of DO values, as available, for propagation each of the eight DO-sensitive fish species (Table 2-1).

- **Minimum Suitability Thresholds** – The minimum suitability threshold represents a condition in which acute mortality will occur for at least one sensitive species in the Delaware Estuary. Functionally, this value represents the highest lethal threshold found in the literature. Below these thresholds, acute mortality may occur under certain conditions such that water quality can be characterized as unsuitable for propagation.
- **Upper DO Thresholds** – The upper threshold is defined as the DO value above which no additional benefit from increased DO is expected. Functionally, this represents the highest value found in the literature where a Delaware Estuary DO-sensitive species showed a DO response. Above these values, there does not appear to be any additional benefit in terms of propagation success.
- **Protective values** – These are DO values between the minimum suitability and upper thresholds that have been deemed protective in various contexts and circumstances. Protective values depend on the timing, frequency, and duration of exposure to specific DO levels within the suitable range.

**Table 2-1: Key Suitability Thresholds for DO-Sensitive Fish in Delaware Estuary**

Species	Stage	DO	Type	Source	Notes
American Shad	Adult	5.0	Protective	Walburg and Nichols 1967 as in Stier and Crance 1985	Habitat suitability index cited observational study that found DO was 5 mg/L or more throughout spawning areas.
American Shad	Egg & Larval	5.0	Minimum*	Marcy 1976 as in Stier and Crance 1985	Habitat suitability index cited observational study that found no shad eggs at DO less than 5 mg/L. *
American Shad	Juvenile	4.0	Minimum	Tagatz 1961	Experimental study found no mortalities occurred when dissolved oxygen was maintained between 2 and 4 mg/L.
Atlantic Sturgeon	Juvenile	4.3	Minimum	EPA 2003 / NOAA 2017	EPA developed Criteria Maximum Concentration of 4.3 mg/L at high temperatures (>29 degrees C) and 3.2 mg/L at normal temperatures. Value of 4.3 mg/L cited by NOAA in critical habitat designation.
Atlantic Sturgeon	Juvenile	5.0	Protective	EPA 2003 / Moberg and DeLucia 2016	Interpretation of experimental studies concluded 60% saturation level (5 mg/L @25C) would protect sturgeon from nonlethal effects.
Atlantic Sturgeon	Juvenile	<5.0 for >30d	Protective	NOAA Fisheries 2017	Interpretation of experimental studies concluded DO less than 5.0 mg/L for longer than 30 days is less likely to support rearing when water temperature is greater than 25 °C.
Atlantic Sturgeon	Juvenile	5.9	Upper Threshold	Niklitschek and Secor 2009b	Bioenergetics modeling of experimental results showed max growth rate achieved at 5.5; max metabolic rates at 5.9 mg/L.
Atlantic Sturgeon	Juvenile	6.0	Upper Threshold	NOAA Fisheries 2017	Interpretation of experimental studies concluded 6.0 mg/L likely supports juvenile rearing habitat.

## Linking Aquatic Life Uses with DO Conditions in the Delaware River Estuary

Species	Stage	DO	Type	Source	Notes
Channel Catfish	Adult	5.0	Protective	Andrews et al. 1973; Carlson et al. 1974 as in McMahon and Terrell 1982	Habitat suitability index cited experimental studies that found DO levels of 5.0 mg/L were adequate for growth and survival.
Channel Catfish	Adult	7.0	Upper Threshold	Andrews et al. 1973; Carlson et al. 1974 as in McMahon and Terrell 1982	Habitat suitability index cited experimental studies that found DO levels $\geq 7.0$ mg/L were optimal.
Channel Catfish	Egg & Larval	4.2	Minimum*	Carlson et al. 1974	Experimental study found decreased hatching success and survival.*
Channel Catfish	Juvenile	5.0	Protective	Andrews et al. 1973; Carlson et al. 1974 as in McMahon and Terrell 1982	Habitat suitability index cited experimental studies that found DO levels of 5.0 mg/L were adequate for growth and survival.
Largemouth Bass	Juvenile	4.0	Minimum	Stewart et al. 1967	Experimental study found growth substantially reduced at 26C; the value of 4.0 mg/L is commonly applied as a minimum DO to support warmwater fisheries.
Shortnose Sturgeon	Juvenile	4.3	Minimum	EPA 2003	EPA developed Criteria Maximum Concentrations of 4.3 mg/L at high temperatures (>29 degrees C) and 3.2 mg/L at normal temperatures.
Striped Bass	Egg & Larval	5.0	Minimum*	Turner and Farley 1971	Experimental study found decreased hatching success and survival.*
Striped Bass	Juvenile	4.0	Protective	Brandt et al. 2009	Experimental study found lowered consumption and growth.
Striped Bass	Juvenile	5.0	Protective	Krouse 1968 as in Bain and Bain 1982	Habitat suitability index cited an experimental study that found high survival.

## Linking Aquatic Life Uses with DO Conditions in the Delaware River Estuary

Species	Stage	DO	Type	Source	Notes
White Perch	Adult	4.0	Minimum	Meldrim, Gift, and Petrosky 1974	Experimental study found avoidance of areas with this DO.
White Perch	Juvenile	6.3	Upper Threshold	Hanks and Secor 2011	Bioenergetics modeling of experimental study found growth threshold effect in this range.
Yellow Perch	Adult	5.0	Protective	Krieger et al. 1983	Habitat suitability index concluded 5 mg/L would be lower optimum limit.
Yellow Perch	Juvenile	5.0	Protective	Krieger et al. 1983	Habitat suitability index concluded 5 mg/L would be lower optimum limit.
Yellow Perch	Juvenile	7.0	Upper Threshold	Thorpe 1977	Literature review found restricted activity.

\* applicable during critical spawning and nursery season (March01 through June30)

Bounding thresholds that define suitability range over all species.

Given the overlap of spatial and temporal distribution (Figure 2-1), it is relatively simple to identify the most stringent (highest) DO thresholds that define a suitability range applicable to all eight DO-sensitive fish species. These bounding thresholds are shaded in Figure 2-2.

- Minimum Suitability Threshold of 4.3 mg/L

The value of 4.3 mg/L is driven by the minimum values for juveniles of both sturgeon species, which is supported by USEPA criteria establishment (EPA 2003) and NOAA Fisheries critical habitat designation (NOAA 2017) as discussed below. Similarly, the value of 4.0 mg/L, identified as a minimum suitability threshold for juvenile American Shad, Largemouth Bass and White Perch, is commonly applied as a minimum DO to support warmwater fisheries.

The USEPA established DO criteria for the Chesapeake Bay (EPA 2003 and EPA 2017) based on CMCs<sup>2</sup> of 3.2 and 4.3 mg/L calculated for non-stressful and stressful temperatures, respectively, specifically designed to support “survival of threatened/endangered sturgeon species” (EPA 2003, p.xiv). The report lists Shortnose Sturgeon and Atlantic Sturgeon as the listed sturgeon species that would be protected by the 3.2 mg/L criterion, and states that Shortnose Sturgeon require a minimum of 4.3 mg/L under stressful temperatures defined as those above 29°C. EPA relied on Jenkins (1993), Secor and Gunderson (1998), Secor and Nilitschek (2003), and Campbell and Goodman (2003), as described in **Error! Reference source not found..** Since summer water temperatures in the Delaware Estuary typically reach 29°C, DRBC selected 4.3 mg/L as a minimum suitability level in order to be protective under all temperature conditions. Furthermore, the same research indicates that Atlantic Sturgeon is more sensitive to high temperatures; the stressful temperature for Atlantic Sturgeon may be 26°C, which is encountered much more frequently.

In its designation of critical habitat for Atlantic Sturgeon (NOAA 2017), NOAA Fisheries described “physical or biological features essential for conservation that may require special management considerations or protection” (pp. 39217-39219). With regard to the New York Bight and Chesapeake Bay Atlantic Sturgeon populations,<sup>3</sup> NOAA identified a number of PBFs<sup>4</sup> essential to conservation of Atlantic Sturgeon, including water quality. Importantly, NOAA states that “these PBFs may be ephemeral or vary spatially across time. Thus, areas designated as critical habitat are not required to have the indicated values at all times and within all parts of the area” (p.39219). As shown in Table 2-1, DRBC derived three key suitability thresholds from NOAA Fisheries’ critical habitat designation PBF description, including the minimum suitability value of 4.3 mg/L. Below is

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<sup>2</sup> CMC = Criteria Minimum Concentration

<sup>3</sup> In the parlance of NOAA Fisheries, distinct populations are referenced as DPSs (Distinct Population Segments).

<sup>4</sup> Physical and biological features are referenced by NOAA as PBFs.

what NOAA's critical habitat designation said regarding water quality specifically as a PBF to support Atlantic Sturgeon conservation.

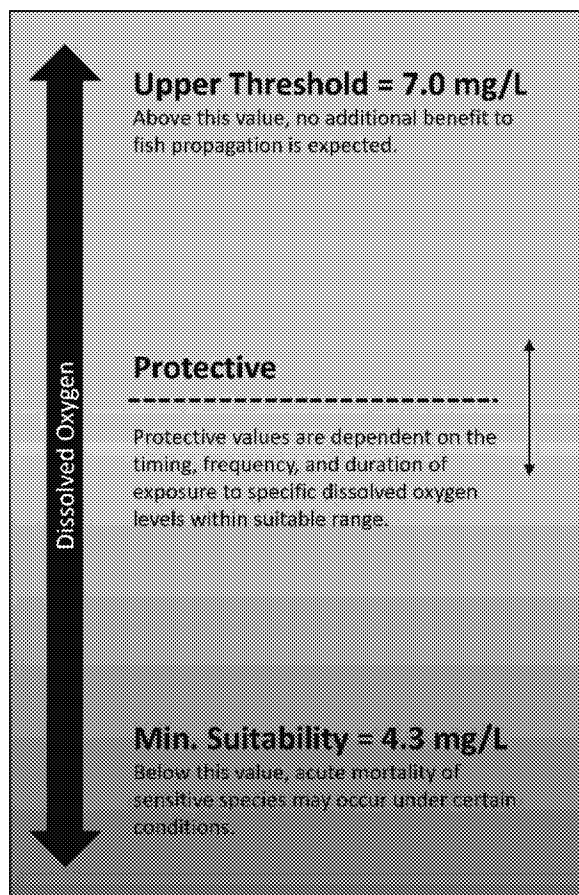
"Water quality conditions, especially in the bottom meter of the water column, between the river mouths and spawning sites with temperature and oxygen values that support: (1) Spawning; (2) annual and inter-annual adult, subadult, larval, and juvenile survival; and (3) larval, juvenile, and subadult growth, development, and recruitment. Appropriate temperature and oxygen values will vary interdependently, and depending on salinity in a particular habitat. For example, 6.0 mg/L DO or greater likely supports juvenile rearing habitat, whereas DO less than 5.0 mg/L for longer than 30 days is less likely to support rearing when water temperature is greater than 25 °C. In temperatures greater than 26 °C, DO greater than 4.3 mg/L is needed to protect survival and growth." (NOAA 2017, p.39219)

- Upper DO Threshold of 7.0 mg/L

A literature review of several juvenile Yellow Perch studies revealed restricted activity at DO below 7.0 mg/L (Thorpe 1977), and the optimal DO for Channel Catfish was also determined to be 7.0 mg/L (e.g., Andrews et al. 1973). The United States Fish and Wildlife Service (USFWS) habitat suitability index for channel catfish concludes a DO concentration of 7.0 mg/L is optimal (McMahon and Terrell 1982). Bioenergetics modeling of experimental studies showed juvenile White Perch exhibited reduced growth at DO below 6.3 mg/L (Hanks and Secor 2011). For these reasons, DRBC, while juvenile Atlantic Sturgeon exhibited reduced metabolism at DO below 5.9 mg/L (Niklitschek and Secor 2009b). DRBC therefore selected the value of 7.0 mg/L as the level of DO above which additional DO is not likely to benefit any of the fish species in the Delaware Estuary.

- Minimum Suitability Threshold of 5.0 mg/L for spawning

The value of 5.0 mg/L as a minimum DO to support spawning is supported by data for both American Shad (Stier and Crance 1985) and Striped Bass (Turner and Farley 1971). The USFWS habitat suitability index for American shad cites observational studies that found no shad eggs at DO levels less than 5.0 mg/L and concludes that DO concentrations of 5 mg/L or more are required throughout the spawning area (Stier and Crance 1985). An experimental study found decreased survival of striped bass eggs and larvae at DO concentrations less than 5 mg/L (Turner and Farley 1971).



**Figure 2-3: Conceptual Model Relating Aquatic Life Suitability to Dissolved Oxygen Levels**

These bounding thresholds were used to develop a DO gradient for the protection of fish propagation in the Delaware Estuary (Figure 2-3). In the Delaware Estuary, DO levels are relevant to the support of aquatic life use up to a level of 7.0 mg/L. Management scenarios that result in more of the estuary exhibiting higher DO levels for longer periods of time, up to a level of 7.0 mg/L, can be expected to enhance support for aquatic life uses, and in particular for propagation of DO-sensitive fish species. On the other hand, management scenarios that result in DO levels that dip below 4.3 mg/L in the summer when water temperatures regularly exceed 26 °C will not fully support fish propagation in the Delaware Estuary.

It is important to note that, in defining this conceptual model, DRBC is not suggesting that the value of 4.3 mg/L or 7.0 mg/L be established as a criterion to support aquatic life uses. Rather, protective DO values can be identified that depend on the timing, frequency and duration of exposure to DO levels within the range of 4.3 mg/L to 7.0 mg/L that will form the basis for criteria to support aquatic life uses in the Delaware Estuary.

Within the suitability range, Table 2-1 shows a number of relevant protective values for various species, including Atlantic Sturgeon. The Atlantic Sturgeon is a key DO-sensitive species in relation to Delaware Estuary DO. Once abundant, their populations crashed in the 1900s because of overharvesting, habitat destruction, poor water quality, and commercial shipping. In 2012, NOAA Fisheries (then the National Marine Fisheries Service) designated the Atlantic Sturgeon an endangered species and in August 2017, the Delaware Estuary was designated as critical habitat for the New York Bight Distinct Population Segment of Atlantic Sturgeon (NOAA 2017). It should be no surprise that the minimum suitability value of 4.3 mg/L was driven by the water quality needs of juvenile Atlantic Sturgeon. The protective value of 5.0 mg/L identified for Atlantic Sturgeon is supported by multiple agencies and researchers.

- In establishing criteria for the Chesapeake Bay (EPA 2003), EPA deemed that 60% DO saturation (or 5 mg/L at 25°C) would be protective of non-lethal effects on Atlantic Sturgeon (citing data from Secor and Niklitschek 2001). The threshold of 5.0 mg/L was applied as an instantaneous minimum criteria applicable from February 1 through May 31.

- The Atlantic State Marine Fisheries Commission reviewed the habitat requirements of diadromous fish species in its 2009 report titled, “Atlantic Coast Diadromous Fish Habitat: A Review of Utilization, Threats, Recommendations for Conservation, and Research Needs” (Green et al. 2009). This report concluded that a DO concentration of 5.0 mg/L would be optimal for Atlantic Sturgeon, citing data from Niklitschek and Secor 2001.
- In 2016, The Nature Conservancy reviewed the impacts of DO on Atlantic Sturgeon in its report titled, “Potential Impacts of Dissolved Oxygen, Salinity and Flow on the Successful Recruitment of Atlantic Sturgeon in the Delaware River” (Moberg and DeLucia 2016). This report cites several of the above studies and those in **Error! Reference source not found.**, and determined that a DO concentration of 5.0 mg/L is suitable for Atlantic Sturgeon.

Note that the same report concluded that DO below 4.0 mg/L is impaired (i.e., unsuitable), and that 6.0 mg/L DO is optimal; these values are very similar to the unsuitable and upper DO thresholds of 4.3 mg/L and 5.9 mg/L identified for Atlantic Sturgeon in Table 2-1.

- A research paper (Schlenger et al. 2013) proposed using “habitat volumes calculated based on threshold physiological tolerances (fixed criteria) and potential growth (bioenergetics) for Atlantic sturgeon *Acipenser oxyrinchus*.” The paper is instructive because its authors included both David Secor and Edwin Niklitschek, two of the most prominent Atlantic Sturgeon researchers, and because it proposed using physiological tolerance thresholds of 3.3 mg/L (“required”) and 5.0 mg/L (“optimal”). These thresholds were labeled as “required and optimal physiological tolerances used for fixed-criteria thresholds of young-of-the-year and yearling Atlantic sturgeon” (Schlenger et al. 2013, Table 1).
- As stated previously, DRBC derived three key suitability thresholds from NOAA Fisheries’ critical habitat designation PBF description. In addition to the minimum suitability value of 4.3 mg/L, DRBC identified the protective value of 5.0 mg/L and the upper threshold value of 6.0 mg/L from the following examples cited (NOAA 2017, p.39219):
  - “In temperatures greater than 26 °C, DO greater than 4.3 mg/L is needed to protect survival and growth.”
  - “DO less than 5.0 mg/L for longer than 30 days is less likely to support rearing when water temperature is greater than 25 °C.”
  - “6.0 mg/L DO or greater likely supports juvenile rearing habitat.”